

2.0 AQUIFER STORAGE AND RECOVERY

This section contains a general overview of the hydrogeology of WRIA 20 and findings related to Aquifer Storage and Recovery potential in the watershed.

2.1 Brief Geologic History of WRIA 20

The Olympic Peninsula contains a variety of notable geologic features. Among the features are a thick sequence of Tertiary basalt (Crescent Formation – erupted between 60 and 50 million years ago [mya]) thrust over younger Tertiary marine sedimentary rocks (sandstones, siltstones and shales deposited between approximately 50 and 24 mya). The uplift of the Olympic Mountains (which thrust the marine sedimentary rocks beneath the basalt) caused regional streams to become incised, creating an erosional landscape of steep, rugged valleys. During the Pleistocene epoch (beginning approximately two million years ago), ice from British Columbia (Cordilleran Ice Sheet) flowed southward into western Washington numerous times. One lobe of the Cordilleran Ice Sheet advanced into the Strait of Juan de Fuca and wrapped around the northern portion of the Olympic Peninsula to the western slope of the peninsula. Alpine glaciers originating in the interior mountains of the Peninsula also advanced during the Pleistocene, further eroding the valleys, and creating much of the landscape characterizing the region today.

2.2 Principal Hydrogeologic Units

The sediments (silts, sands and gravels) deposited in meltwater streams draining alpine glaciers comprise the most important hydrogeologic units in WRIA 20. These overlie bedrock that has little potential for groundwater development.

2.2.1 Unlithified Deposits

The unlithified materials (sedimentary material that has not been converted into coherent, solid rock) present in WRIA 20 include glacially deposited materials (drift [fine and coarse-grained undifferentiated deposits], outwash, and till) and non-glacial deposits (alluvial and fluvial sediments; Figure 1-1). These materials were deposited on top of the lithified marine sedimentary rocks and basalt, primarily in valleys. Till and fine-grained drift generally do not form productive aquifers. Till is a highly heterogeneous, often highly compacted mixture of clay, silt, sand, and gravel that was deposited directly beneath the glacier and generally does not produce a significant amount of water.

A yield of between 10 and 50 gpm is typically sufficient for domestic or small group wells, while the yield of a larger group well is typically much higher (75 to 500 gpm in WRIA 20). The most significant unlithified sediments for water production in WRIA 20 are sand and gravel deposited on top of the marine sedimentary rock and basalt. Sand and gravel can be deposited by present day streams or by meltwater streams draining from glaciers. The most productive glacially-derived deposits are advance outwash sand and gravel, which were deposited as the glacier advanced.

The thickness of the unlithified materials in WRIA 20 ranges from a few feet thick up to about 370 feet thick, but is generally less than 100 feet thick. The transmissivity of the primary water-bearing unlithified materials (coarse sand and gravel) were estimated based on specific capacity information (pumping rate and drawdown) presented on well logs (Golder, 2005a). The transmissivity of the sand and gravel materials was estimated to range from about 10 ft²/d to over 45,000 ft²/d. Well yields in the unlithified materials range from dry wells (no water) completed in fine-grained drift or till materials, to 100 gpm to 300 gpm for larger diameter, properly constructed wells completed in sand and gravel, such as those operated by the City of Forks and the Quileute Indian Tribe.

2.2.2 Lithified Deposits

Lithified deposits in WRIA 20 include marine sedimentary rocks (sandstone, siltstone and shale) and lesser amounts of igneous bedrock (primarily comprised of basalt). The lithified deposits in WRIA 20 are generally of low permeability, and the yield of water is primarily through fractures. In WRIA 20, wells completed in the lithified deposits generally yield small quantities of water (less than five gallons per minute; gpm). Some wells completed in the lithified sediments in WRIA are dry (Golder 2005). The low permeability of these materials limits their ability to transmit large quantities of water and they are not considered further for significant groundwater development or artificial recharge and storage.

2.3 **Recharge Methods**

Conventional aquifer storage and recovery (ASR) involves the use of wells to inject water into an aquifer, where it is storage and later pumped out for use. Several other methods of recharging water have also been used to augment groundwater supply. This section describes methods of recharging groundwater, including surface methods in the unsaturated zone such as spreading basins or dry wells, and underground methods in the saturated zone (wells). Recharge methods are summarized on Table 2-1.

2.3.1 Spreading Basins

Spreading basins are topographically controlled features (e.g., depressions or shallow valleys) underlain by permeable, unsaturated materials such as sand and gravel that can be used to recharge unconfined (water table) aquifers. Recharge water is conveyed to the basin, where it infiltrates and travels through the unsaturated zone to the water table. The recharge water source could be peak streamflows, stormwater runoff, or highly-treated wastewater. Spreading basins are relatively inexpensive to construct and operate, and can be constructed in existing or abandoned gravel pits or other excavations in favorable areas. The recharge water is filtered through the unsaturated zone before reaching the water table.

Some form of pre-treatment system such as oil-water separators or sediment traps may be incorporated into spreading basins to provide some treatment prior to infiltration. Spreading basins may require periodic cleaning or maintenance to remove trapped sediment to prevent clogging of the basin, or service oil-water separators or other treatment facilities.

Spreading basins are currently being evaluated to recharge shallow groundwater in unconfined aquifers that are in direct continuity with surface water as a means to augment flows using groundwater discharge during low-flow periods in the Walla Walla watershed. Peak flows are conveyed using irrigation ditches to spreading basins.

2.3.2 Augmentation of Streamflow with Bank Storage

Bank storage involves infiltration of recharge water, typically peak flows or stormwater, using spreading basins or infiltration canals. The recharge water infiltrates to the groundwater flow system, where it is stored. The recharge water flows under the hydraulic gradient to the aquifer discharge location (rivers or streams). The recharge water discharges to surface water, augmenting the flow.

The volume of water that could potentially be available for augmentation over a three month period is estimated using the following idealized assumptions:

- **Aquifer width** equal to the average valley width, and a representative length;
- **The workable unsaturated zone** (thickness). This is assumed to be 5 feet. The term “workable” refers to the minimum unsaturated zone. When the water table is raised, topographic lows such as ancestral stream channels that define topographic swales will drain any additional rise in the water table effectively limit additional groundwater storage. Because the period of recharge is during the rainy season, this estimate may be high if the unsaturated zone is already fully recharged.
- **Aquifer porosity.** This is the pore space within the aquifer, and is assumed to be 20%;
- Water is recharged until the start of the streamflow augmentation period; and,
- Bank storage is released and augments flow over a three month period (90 days).

Example Theoretical Calculations of Streamflow Augmentation by Artificial Bank Storage

	Hoh River	Big River
Aquifer area (A)	1 mile wide; 10 miles long (from Highway 101 bridge to the confluence of the North and South Forks); = 10 square miles	½ mile wide; 5 miles long; = 2.5 square miles
Workable unsaturated zone thickness (T)	5 feet	
Aquifer porosity (n)	20%	
Theoretically available storage (cubic feet; $V=A*T*n$)	278,784,000 cubic feet	69,696,000 cubic feet
Average streamflow augmentation assuming stored water is released over a 3-month period (cfs; $Q=V/90$ days)	36 cfs	9 cfs

The assumption that groundwater is released from bank storage at a constant rate over 90 days is a highly idealized representation. Actual augmentation discharge will be highest at the start of the augmentation period, immediately after recharge is stopped, and will decline over the duration of the augmentation period. This decay in streamflow augmentation will result in the lowest augmentation occurring late in the summer season, during natural low flows, just when it is most needed.

This method of estimating streamflow augmentation provides a theoretical maximum to frame the range that may be attained. The assumption assumes flooding of the complete floodplain, and values that might actually be realized will probably be significantly less.

2.3.3 Wetlands

Generally, wetlands exist at groundwater discharge points or in locations where recharge rates are very low. Such conditions are not conducive to aquifer recharge. However, under certain conditions, wetlands can be used to infiltrate recharge water similar to spreading basins if the wetland area is above the water table. Wetlands can also be used to filter or “polish” recharge water (such as treated

wastewater) prior to infiltration to improve water quality. The Cities of Yelm and Sequim use wetlands as part of reclaimed water treatment and groundwater recharge.

2.3.4 Dry Wells

Dry wells are small, shallow excavations in permeable materials above the water table that are constructed with a liner or casing. The liner or casing is perforated or has sections of screen that allow recharge water to pass from the drywell to the surrounding unsaturated materials. The recharge water infiltrates through the unsaturated materials to the water table. Dry wells are typically used to infiltrate stormwater. Some form of pre-treatment system such as oil-water separators or sediment traps may be incorporated into dry wells to provide some treatment prior to infiltration, depending on the quality of the stormwater which is dependent upon the nature of the contributing area. Dry wells require periodic cleaning and service to remove trapped sediment and maintain oil-water separators or other treatment systems. Such infiltration may have to comply with Ecology stormwater management rules, and/or regulations protecting groundwater quality.

2.3.5 Wells

Wells can be used to directly recharge groundwater through injection. Wells are particularly suitable for recharging deep, confined aquifers or unconfined aquifers where the unsaturated zone is thick. Recharge wells could be dual-purpose aquifer storage and recovery (ASR) wells that are used for both recharge and pumping, or wells that are used only for recharge in conjunction with other wells that are used for pumping only. Wells are used to recharge groundwater in Walla Walla, Portland, and Salem, and several other cities in the Northwest are evaluating artificial recharge.

Because recharge wells introduce the recharge water directly into the aquifer, no filtration through the unsaturated zone occurs. The recharge water must effectively meet drinking water quality and anti-degradation standards unless a waiver can be obtained, and should have low turbidity (less than one NTU) and low suspended solids concentrations (less than 1 mg/L) to limit clogging of the recharge well and aquifer. The water quality criteria for direct recharge using wells generally require that the recharge water be treated. There are no water treatment plants in WRIA 20. The cost to construct a treatment plant is on the order of \$1,000,000 per 1 million gallons per day (mgd) capacity.

2.4 **Water Sources for Recharge**

Three sources of water for recharge are considered: diversion from stream channel during high flow conditions, stormwater (i.e., overland flow), and reclaimed wastewater.

2.4.1 Peak Flows

Peak flows are a common source of recharge water for artificial recharge projects. Peak flows are used by the Cities of Walla Walla, Salem, and Portland for artificial recharge of drinking water. Peak flows are also being evaluated in the Walla Walla watershed as a means to recharge shallow aquifers to store water that is used to augment streamflow as the groundwater discharges to the streams during low-flow periods of the year.

In WRIA 20, peak flows occur in the late fall and winter, coincident with increased precipitation. Peak flows continue into the early to mid-spring as snowmelt in the higher elevation portions of the WRIA occur. Streamflow hydrographs for the Hoh, Dickey, Sol Duc, Bogachiel, and Calawah Rivers are included in Appendix 2-A.

Water used for direct artificial recharge (such as with injection wells or ASR wells) must meet anti-degradation criteria (WAC 173-200) summarized on Table 2-2. Temporary variances from these regulations may be obtained for periods of up to five years, but must be renewed. Criteria for the issuance of a variance include:

- Benefit to the environment;
- In the interest of human health and the environment; and,
- Impacts will be minimized.

Water used for recharge should also have low turbidity and low suspended solids to limit clogging of recharge wells or infiltration basins. Water quality data for selected constituents are available from the Hoh River. The available water quality criteria are compared to the anti-degradation criteria on. During peak flow periods, the Hoh River contains concentrations of fecal bacteria, turbidity, and high suspended solids that exceed water quality standards for the protection of groundwater. The water quality of other rivers in WRIA 20 is likely similar to the Hoh River, and thus would require treatment to reduce suspended solids and turbidity, and eliminate bacteria prior to direct recharge unless a variance could be obtained. No surface water treatment plants currently exist in WRIA 20 that could treat surface water for direct recharge.

Instream flows have not been set in WRIA 20 at this time. However, several Surface Water Source Limitation (SWSL) letters were written by the Department of Fish and Wildlife in the early 1990's in response to eight surface water right applications for the Sol Duc River and its tributaries (Beaver Creek, Lake Pleasant, and Snider Creek) and the Bogachiel River (Table 2-3). The SWSL letters recommended low-flow provisions for specific periods (e.g., summer) for three of the surface water bodies. Detailed examination of recommendations of water right denials without defined periods and/or discussions with agency personnel may reveal whether the effective instream flow restriction is year round or seasonal. Although no SWSLs have been written in response to groundwater applications, future groundwater applications could be conditioned on instream flow or recommended for denial because of hydraulic continuity and streamflow concerns or fisheries concerns.

The seasonal availability of peak flows to use as recharge water would have to be determined by Ecology in consultation with the Washington Department of Fish and Wildlife (WDFW), tribes, and other stakeholders as part of the water right application process.

2.4.2 Stormwater Runoff

Stormwater runoff can be used to recharge groundwater using infiltration basins or dry wells. Stormwater is typically recharged to the unsaturated zone and allowed to infiltrate to the water table. Because stormwater is typically untreated or minimally treated, water quality may be a concern. Typical constituents in stormwater from urban areas include fecal bacteria, metals, pesticides and herbicides, and hydrocarbons. Stormwater would likely require some form of pretreatment prior to infiltration.

The availability of stormwater as a source of recharge requires further evaluation. It is possible that stormwater runoff may be available in some of the more populated areas of the watershed, such as Forks, where stormwater collection systems are developed or planned. However, the total volume of managed stormwater is not anticipated to be significant because the watershed is largely rural, undeveloped and forested.

2.4.3 Reclaimed Water

Reclaimed water (water collected and treated after use) may be beneficially used for surface infiltration provided the reclaimed water meets the groundwater recharge criteria as measured in the groundwater beneath or down gradient of the recharge site. Reclaimed water used for groundwater recharge shall be at all times of a quality that fully protects public health and the water quality of waters of the state. Reclaimed water that does not meet the groundwater recharge criteria may be beneficially used for surface percolation where the Departments of Health and Ecology have specifically authorized such a use at a lower standard. Reclaimed water may also be used to directly augment streamflow.

Reclaimed water that is used to recharge groundwater using surface infiltration methods must be treated to Class A standards, with an additional step to reduce nitrogen concentrations in oxidized reclaimed water. Reclaimed water can also be used for direct aquifer recharge. The standards for direct aquifer recharge are more stringent than for surface infiltration and include:

- Treatment by reverse osmosis;
- Turbidity less than 0.1 NTU, total nitrogen less than 10 mg/L, and total organic carbon less than 1 mg/L;
- The recharge location must be greater than 2,000 feet from other wells;
- The recharged water must remain in the aquifer for at least 12 months; and,
- The reclaimed water must meet drinking water criteria and state groundwater standards.

Reclaimed water intended for beneficial reuse may be discharged for streamflow augmentation provided the reclaimed water meets the requirements of the federal water pollution control act, (Chapter 90.48 RCW) and is incorporated within a sewer or water comprehensive plan as applicable, adopted by the applicable local government, and approved by the Departments of Health and Ecology.

Reclaimed water is presently used to recharge groundwater in the Forks Prairie area. The City of Forks operates the only wastewater treatment plant in WRIA 20. Reclaimed water from the City's wastewater treatment plant is currently infiltrated to groundwater using several infiltration basins. The depth to water near the wastewater treatment plant is about 80 to 90 feet below ground. Therefore, the reclaimed water passes through a thick section of unsaturated sand and gravel before reaching the water table. The infiltration ponds are down gradient of the City's wellfield.

2.5 Evaluation of Aquifer Storage and Recovery Potential in WRIA 20

ASR potential was evaluated for selected areas of WRIA 20. Hydrogeologic characteristics of the seven areas selected for the assessment in the first step were evaluated in relation to ASR applications. A preliminary assessment of groundwater development and storage alternatives were developed and are summarized in this section.

2.5.1 General Findings

Conventional Aquifer Storage and Recovery (ASR) – involving the direct injection of water into an aquifer – has limited potential in WRIA 20. The findings of the evaluation are summarized in Table 2-4. ASR is not considered highly feasible in the area because the high cost of treatment required for

operational considerations and to meet state groundwater antidegradation rules. A suitable source typically involves surface water that has been treated to potable standards. Capital costs of such a plant are usually on the order of one million dollars per 1 million gallons per day (mgd) capacity.

In addition to the cost of water treatment, ASR studies would require detailed hydrogeological evaluations to fully evaluate the technical feasibility of recharge and storage, including:

- Recharge water availability;
- Recharge water quality and compatibility with the native groundwater and aquifer mass;
- Aquifer boundaries;
- Hydraulic continuity with surface water;
- Recharge and storage capacity of the aquifer; and,
- Potential effects on other groundwater users.

Theoretical maximum estimates of streamflow augmentation based on the maximum capacity of alluvial floodplain aquifers and idealized release of that water during low flow periods results in streamflow augmentation of 11-29 cfs on the Big River, and 61-127 cfs on the Upper Hoh. Actual augmentation results are expected to be significantly lower than these estimates. Recharge to floodplains would require diversion structures on the river and conveyance channels to recharge sites.

Individual sites evaluated are:

- Forks Prairie;
- Quillayute Prairie;
- Three Rivers;
- Lower and Upper Hoh (two separate areas);
- Beaver/Lake Pleasant; and,
- Ozette/Trout Creek.

General information related to ASR considerations is presented in separate sections below. More detailed and broader ranging hydrogeologic information on the Forks and Quillayute Prairies and Three Rivers areas is contained in Chapter 4. Considerations related to the Upper Hoh are not presented in this chapter, but are fully contained in Chapter 4.

2.5.2 Forks Prairie

Forks Prairie is a flat to gently sloping terrace that is located between the Calawah and Bogachiel Rivers, and an upland area south of the City of Forks. It extends from the confluence of the Bogachiel and Calawah Rivers, east to the confluence of the North and South Forks of the Calawah River. Portions of the Forks Prairie area extend into the Calawah and Bogachiel Subbasins. Drinking water for much of the Forks Prairie area is supplied by the City of Forks by operation of a wellfield on the northeast side of Forks. The geologic units in the Forks Prairie area include alluvial materials in the channels of the rivers, glacial outwash, and marine sedimentary rocks and undifferentiated glacial drift in the upland areas adjacent to the prairie.

Most of the groundwater for municipal and domestic use in WRIA 20 is obtained from the Forks Prairie area. The City of Forks obtains its water supply from five wells located in Sec. 9, T28N,

R13W. Information is also available from two of the water supply wells and two monitoring wells installed at the City of Forks wastewater treatment plant in Sec. 9, T28N, R13W, about one mile west of the water supply wells. The total thickness of unlithified sediments in the Forks Prairie area is estimated to range between 100-200 feet. The wells are completed in confined, coarse sand and gravel aquifer that is about 10 to 15 feet thick, at a depth of about 110 feet below ground. The aquifer appears to be moderately to highly permeable, and well yields are between 100 and 400 gpm. The coarse sand and gravel aquifer is overlain by glacial till with lenses of sand and gravel. The extent of the aquifer is uncertain because few well logs are available in the Forks Prairie area. The wells are terminated in clayey sand and gravel.

Aquifer testing using the City of Forks wells suggest that the range of influence of pumping is limited (i.e., less than 2,000 feet) due to the high aquifer transmissivity and the leaky nature of the aquifer (see Chapter 4). (Transmissivity is the ability of geologic materials to transmit water. It is the product of hydraulic conductivity [K; ft/day] of the material, times the thickness of the formation [feet; Freeze and Cherry, 1979].)

The groundwater elevation in the sand and gravel aquifer is about 200 feet msl, or about 80 to 90 feet below ground, based on water levels in the City wells. The groundwater elevation in the wells is about 10 to 30 feet higher than the elevation of the Calawah River.

Artificial recharge and storage in the confined aquifer is considered limited because available information indicates that the aquifer does not hold water through the summer for effective seasonal storage (see Chapter 4).

2.5.3 Quillayute Prairie

Quillayute Prairie and Little Quillayute Prairie are flat to gently sloping terraces that are located between the Dickey and Sol Duc Rivers on the upland north of Quillayute Road. Quillayute Prairie extends from the confluence of the Dickey and Quillayute Rivers east to about the east side of Sec. 9, T28N, R13W. The Quillayute Prairie area extends into the Sol Duc and Dickey subbasins. Drinking water in the Quillayute Prairie area is supplied by individual exempt wells and several Group B water systems that rely on wells.

The geologic units in the Quillayute Prairie area include alluvial materials in the channels of the rivers, and glacial till and drift and marine sedimentary rocks in the upland areas adjacent to the prairie. Alluvium, and permeable glacial materials (outwash) underlying till, are the principal aquifers in the area. The Quillayute Prairie is capped by till and underlain by higher permeability aquifer materials that may be older alluvium and/or glacial outwash materials.

The principal water-bearing zones in the Quillayute Prairie area are five to 20 foot thick lenses of sand and gravel that form confined aquifers or water-bearing zones within till and fine-grained glacial drift materials. The lateral extent and continuity of these zones is unknown. Groundwater elevations range between about sea level and 175 feet msl. Well yields range from about four to 70 gpm. The transmissivity of the aquifer materials ranges from about 30 to 7,600 ft²/d, with a median transmissivity of 760 ft²/d, indicating the aquifer materials are low to moderately permeability. No information on water quality for the sand and gravel aquifers is available, except for comments on a few well logs, such as “soft” water and “irony” water.

Some wells in the Quillayute Prairie area are completed in marine sedimentary rocks. Well yields from the marine sedimentary rock are low, ranging from about one gpm to five gpm, while some wells were dry. This is typical for wells completed in lithified materials in WRIA 20.

Artificial recharge and storage in the confined aquifer(s) may be technically feasible if a suitable source of recharge is available. However, the potential for ASR in the Quillayute Prairie area is estimated to be moderate due to the limited storage capacity of the aquifers and high degree of hydraulic continuity with streams (Table 2-4). Geotechnical considerations related to overpressurizing the aquifer and associated ground stability where the aquifer may discharge at the bottom of slopes surrounding the prairie may also be a concern.

2.5.4 Three Rivers Area

The Three Rivers area is in the vicinity of the confluence of the Bogachiel and Sol Duc Rivers that form the Quillayute River. Drinking water in this area is supplied by several Group A and B water systems and individual exempt wells. The Quileute Tribe also operates two wells in this area that supply water via a pipeline to the Quileute Reservation.

The geologic units in the Three Rivers area include unconsolidated alluvial materials (sand and gravel, glacial outwash and drift) overlying lithified marine sedimentary rock (shale and sandstone). The alluvial sand and gravel forms productive unconfined aquifers in the Three Rivers area. The underlying marine sedimentary rocks form a poor aquifer, with low well yields (less than 1 gpm) or dry wells.

The Quileute Tribe has drilled numerous test wells from Thunder Field, to the area east of the confluence of the Sol Duc and Bogachiel Rivers as part of their development of a reliable water supply for their Reservation, which is located west of the Three Rivers area. The test well information, along with other water well logs in the area, indicate the presence of moderately to highly productive sand and gravel aquifers(s), that are alluvial materials deposited by the rivers or glacial outwash. Observations near the Quileute Tribe's wells in Sec. 20, T28N, R14W indicate that a portion of the aquifer discharges to springs along the bank of the Bogachiel River.

The sand and gravel deposits occur between about 20 to 70 feet below ground, with a saturated thickness of about 10 to 30 feet. The sand and gravel deposits do not extend below sea level, and appear to pinch out to the east in Sec. 22, T28N, R14W.

Aquifer test data presented on the well logs indicate the transmissivity of the sand and gravel aquifer is about 600 to 72,000 ft²/d, with a median transmissivity of about 3,800 ft²/d, indicating the aquifer is generally moderately to highly permeable. The transmissivity of the sand and gravel aquifer is confirmed by pumping tests conducted on two wells drilled for the Quileute reservation in Sec. 20, T28N, R14W. The transmissivity estimated from the pumping tests was about 65,000 to 80,000 ft²/d, and the storativity was estimated to be about 0.02. (The specific storage [S_s ; ft⁻¹] of an aquifer is the unit volume of water released from storage under a unit decline in hydraulic head [Freeze and Cherry, 1979]. Storativity [S] is defined as the specific storage times the thickness of the aquifer, and is unitless.)

Interferences between pumping wells in the Three Rivers and the Quillayute Prairie are not expected to exist because of the high storativity (which may reflect a leaky aquifer characteristic, or not being well-confined), and high transmissivity. The aquifers of these two areas are also interpreted to be different (i.e., younger alluvium in the Three Rivers area, and older alluvium and/or glacial outwash in the Quillayute Prairie). These aquifers may also have a relatively high degree of continuity with streams, in which case the Sol Duc River that separates the Three Rivers and Quillayute Prairie areas would further attenuate the transmission of pressure pulses between the two areas.

Groundwater level observations made during pumping tests conducted on two test wells drilled at Thunder Field indicate that the sand and gravel aquifer is tidally influenced at least to this area (about River Mile 2 on the Quillayute River). Tidally-influenced groundwater level fluctuations of 0.5 to 2.5 feet were observed during testing of the wells, which occurred during a period of extreme tidal flux. The tidal fluctuation in the Quillayute River was about 3 to 4 feet. The upstream limit of tidally-influenced groundwater and surface water is not known, but groundwater levels in Sec. 20, T28N, R14W, near the confluence of the Sol Duc and Bogachiel Rivers, do not appear to be tidally influenced.

Water quality in the sand and gravel aquifer appears to be good based on existing information. Manganese and iron concentrations were below the secondary water quality standard in all of the Quileute Tribe test wells. Several well logs from the Three Rivers area contained comments on high iron concentrations. Chloride concentrations were measured during testing of wells located at Thunder Field near the Quillayute River, where the aquifer is tidally influenced. The testing indicated chloride concentrations were between about 6 mg/L and 50 mg/L, well below the secondary standard of 250 mg/L. It is not clear whether this salinity is related to marine saline influences. However, the lower reaches of valleys are commonly discharge locations for deep seated regional groundwater flow paths, and such salinity may be related to mineralize groundwater discharging from bedrock.

The sand and gravel outwash materials in the Three Rivers area appear to be suitable for development of additional groundwater. The marine sedimentary rocks are not favorable for groundwater development.

Artificial recharge for storage of drinking water may not be feasible because of the unconfined aquifer(s) and the high degree of hydraulic continuity with surface water. Additional evaluation is needed to confirm whether artificial recharge is feasible (Table 2-4).

2.5.5 Lower Hoh

The Lower Hoh area considered in this evaluation is the south side of the river, extending upstream from the mouth of the river to the Highway 101 Bridge. The Lower Hoh area is in the Hoh subbasin. Drinking water is supplied by individual exempt wells and one Group B system at a campground. Groundwater is the source of drinking water at the Hoh Reservation at the mouth of the river.

The geologic units in the Lower Hoh area include unlithified alluvial and glacial outwash sediments overlying marine sedimentary rocks. Information on the hydrogeologic conditions in the area was obtained from well logs, the USGS and consultant reports on groundwater development for the Hoh Reservation.

The principal aquifer in the Lower Hoh area is glacial outwash deposits. The glacial outwash is about 5 to 20 feet thick. The outwash is overlain by fine-grained terrace deposits and by fine-grained glacial drift, and underlain by low-permeability marine sedimentary rocks. In the vicinity of the Hoh Reservation, several large springs discharge from the glacial outwash where the Hoh River has eroded terrace deposits and exposed the outwash. These springs discharge up to about 250 gpm to 500 gpm. Well yields in the outwash range from about 5 to 75 gallons per minute. The highest well yields were from wells installed upgradient of the springs. Well yields are limited by the low saturated thickness and discontinuity of permeable lenses in the outwash materials in the Lower Hoh area.

In some areas (particularly in the vicinity of River Miles 3 and 4), the outwash is confined below fine-grained glacial drift materials, with groundwater levels ranging from about 10 feet below ground to flowing artesian, or about 50 to 90 feet above the water bearing zones intersected in the wells. The

glacial outwash is discontinuous. Several wells drilled in Sec. 4, T26N, R12W did not intersect outwash or other water-bearing materials and were abandoned. The marine sedimentary rocks underlying the outwash material are fine-grained and no wells in the Lower Hoh area were completed in the marine sedimentary rock. It is likely that well yields in the marine sedimentary rock would be in the range of less than one gpm to three gpm, based on observations from wells completed in similar materials in other areas of WRIA 20.

Limited groundwater quality sampling from test wells drilled on the Hoh Reservation indicate groundwater from the outwash aquifer has low pH of about 5.5 to 6.0, which is below the secondary standard of 6.5, and may have iron concentrations greater than the secondary standard of 0.3 mg/L. Low pH water increases the potential to leach lead and copper from distribution systems. Water quality samples from a Group B well (Hoh campground) indicated iron and manganese concentrations below the secondary water quality standard of 0.3 mg/L and 0.05 mg/L, respectively.

Storage of water in the Lower Hoh area does not appear to be feasible because of the limited aquifer capacity and continuity of the aquifer with the Hoh River (Table 2-4). Storage concepts for the Upper Hoh are presented in Chapter 5.

2.5.6 Beaver/Lake Pleasant

The Beaver/Lake Pleasant area is located in the Sol Duc subbasin between Tyee Hill and the Sol Duc River (Figures 2-1). Conditions of this area also probably characterize the hydrogeology of the Sappho area immediately upstream. Lake Pleasant is located between Upper Lake Creek and Lower Lake Creek, which flows into the Sol Duc River. The area includes the town of Beaver (Tyee). Drinking water in the area is supplied by individual exempt wells, and several Group A and B groundwater systems. Information on wells was obtained from Ecology's well log database and the Washington Department of Health, as filed by well drillers and water system owners, respectively (Figure 2-1; plotted to the resolution of the available data). Some of the data is duplicated in the two systems and may therefore be represented in duplicate in figure 2-1.

The geologic units exposed at the surface in the Beaver/Lake Pleasant area include unconsolidated alluvial materials, glacial outwash, and glacial till in the Sol Duc valley (Tyee Prairie and Beaver Prairie), and lithified fine-grained marine sedimentary rock and glacial till in the upland areas (Tyee, Shuwah and Beaver Hills).

Glacial outwash is the principal water bearing material in the area. Well logs indicate several lenses of confined water-bearing sand and gravel that occur between about 20 feet and 180 feet below ground, that are overlain by glacial till and separated by glacial till or other fine-grained glacial drift materials (Figure 2-2). The sand and gravel lenses are commonly about 5 to 40 feet thick. Groundwater elevations in the sand and gravel range between about 228 and 526 feet msl. A small amount of groundwater also occurs in the fine-grained marine sedimentary rock, however most wells completed in the marine sedimentary rock were dry, and were abandoned.

Wells in the Beaver/Lake Pleasant area produce between about 1 and 60 gpm (Figure 2-3). There is an area of dry or low-yielding wells on the south east side of the lake, in Sections 25, 35, and 36 (T30N, R13W). In this area, glacial outwash sediments are thin or absent, and clay and sedimentary rocks are at or near the ground surface. The transmissivity of the sand and gravel ranges between about 60 to 10,400 ft²/d, with a median transmissivity of about 800 ft²/d, indicating the sand and gravel aquifer has low to moderate permeability. The continuity of groundwater and surface water near Lake Pleasant is unknown. There is potential for Groundwater Under the Influence of surface

water (GUI) to occur if wells are located in close proximity to surface water, such as Lake Pleasant, and pumping induces recharge from surface water.

Groundwater in the Beaver/Lake Pleasant Area meets the secondary water quality standards for iron and manganese based on sampling conducted at two Group A water systems.

Surface Water Source Limitation letters were filed by WDFW over concerns for Coho salmon for three surface water right applications for water from Lake Pleasant (Table 2-3). Since the letters were filed, most of the applications have been processed and are either in the permit stage or have been certificated.

The sand and gravel outwash materials in the Beaver/Lake Pleasant area host the only developable aquifer zones. However, Planning Unit members report that several attempts are commonly required before successfully installing productive wells (e.g., several dry wells are installed before a productive aquifer zone is encountered). This is a costly process for the individual commissioning the well. The marine sedimentary rocks are not favorable for groundwater development. Therefore, the potential for implementing groundwater storage in the area is estimated to be low (Table 2-4).

The difficulty in siting wells that intersect productive portions of the aquifer system is a result of the dominance of finer-grained sediments. The inability to correlate strata between well logs may also be an effect of the discontinuous nature of the more transmissive layers. A geophysical survey using multiple parameters may provide a better characterization of the stratigraphy and improve the probability of success in installing productive wells. Geophysical parameters that could be considered include seismic and electromagnetic surveys. A survey grid involving several cross-valley sections along with a section extending along the axis of the valley to tie the cross-valley surveys may be most productive. Site accessibility will exert a significant control on the survey orientation. Some electromagnetic survey methods are subject to interference from cultural influences, such as buried pipelines and power lines. Survey lines should be oriented to intersect existing well logs where possible for calibration purposes.

2.5.7 Ozette and Trout Creek Area

The Ozette area is located on the east shore of Lake Ozette in the Ozette subbasin. Planning Unit concerns in this area are related to drinking water and maintenance of summer low streamflows. The Trout Creek area is located on the northeast side of Lake Ozette, northeast of Umbrella Creek. This area is relatively undeveloped. The shallow depth and limited extent of unconsolidated sediments limits easily developable groundwater supplies. Because of this, some residents rely on water taken directly from the lake without treatment or disinfection, which presents a health risk from naturally occurring pathogens (e.g., *Giardia*). Drinking water is also supplied by individual exempt wells, and a Group A water system and a Group B water system that rely on wells at the north end of the lake.

Hydrogeologic information in the Ozette area is limited to a few well logs and existing geologic maps. No well logs are available for the Trout creek area. The geologic units exposed at the surface include unlithified alluvial materials (silt, sand, and gravel) near Ozette and Swan Bay, and fine-grained glacial drift over most of the east shore of Lake Ozette. The glacial drift overlies lithified fine-grained marine sedimentary rock. Information presented on well logs indicates the unlithified materials range in thickness from less than five feet to over 100 feet.

Wells completed in both the glacial drift and marine sedimentary rock yield small quantities of water to wells (less than five to 10 gpm), or are dry. The estimated transmissivity from three wells that had aquifer test information indicates a transmissivity of about 25 to 800 ft²/d, indicating low to moderate

permeability. Groundwater quality data from the Ozette Campground well indicates iron and manganese concentrations are above the secondary water quality standards of 0.3 and 0.05 mg/L, respectively.

Siting of wells could consider large scale (e.g., mile-scale) geomorphic (topographic) features that may indicate the presence of sediment-filled bedrock valleys. Siting of wells close to surface water could inadvertently induce infiltration of surface water and possible associated pathogens. The Washington Department of Health considers wells that are closer than 200 feet from surface water and shallower than 50 feet in depth to be susceptible to the influence of surface water, and recommends evaluation of such sources for health concerns.

Because bedrock is relatively shallow in this area, conventional aquifer storage is not considered feasible. Two alternative methods of storage considered in the Ozette area are bank storage for streamflow augmentation, and the use of forest roads along the river valleys to impound water, creating wetlands that could be used for storage or habitat enhancement.

One approach for using bank storage involves the infiltration of recharge water, typically peak flows or stormwater, using spreading basins or infiltration canals, as described in Section 2.3.2 (Augmentation of Streamflow with Bank Storage). The recharge water infiltrates to the groundwater flow system, where it is stored. The recharge water flows under the hydraulic gradient to the aquifer discharge location (rivers or streams). The recharge water discharges to surface water, augmenting the flow.

The theoretical volume of water that could potentially be available for augmentation over a three month period is estimated using the following assumptions:

- A valley (aquifer) width of half a mile and a length of five miles;
- Aquifer porosity of 20%;
- A workable unsaturated zone of five feet;
- Water is recharged until the start of the augmentation period; and
- Flow is augmented over a three month period.

Using these assumptions, the average augmentation discharge is estimated to be about 9 cfs. The actual augmentation discharge will be highest at the start of the augmentation period, immediately after recharge is stopped, and will decline over the duration of the augmentation period. The estimate of streamflow augmentation should be considered as a theoretical maximum to frame the range that may be attained. The assumption assumes flooding of the complete floodplain, and values that might actually be realized will probably be significantly less.

Development of groundwater storage in the Ozette/Trout Creek area may be technically feasible. However, the potential for implementing more conventional methods of groundwater storage in the area is estimated to be low (Table 2-4).

An alternative approach to increasing bank storage is to maintain the existing groundwater storage through control of downcutting of the stream channel (degradation). Big River is the largest stream in the Ozette Subbasin. A geomorphological assessment of this river was selected by the Planning Unit for detailed analysis in Step 2 of this storage assessment, which is presented in the next chapter.